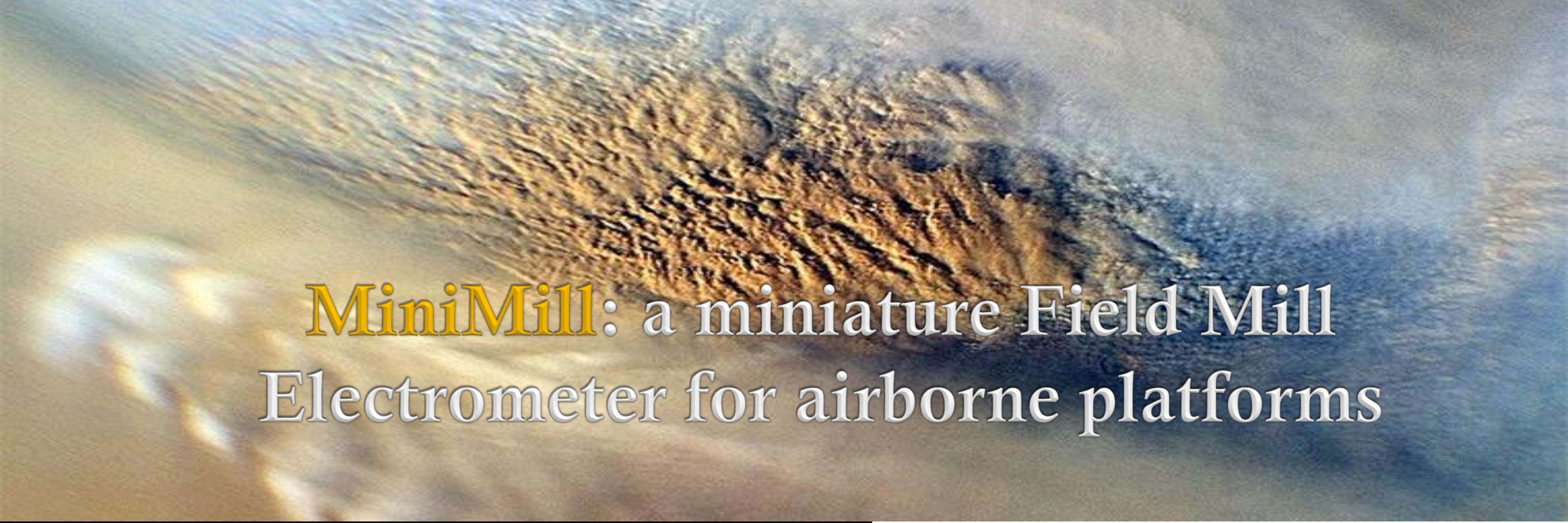
MiniMill: a miniature Field Mill Electrometer for airborne platforms



Img: *NASA Mars Reconnaissance Orbiter*

Vasiliki Daskalopoulou,

V. Spanakis *and* **Th. Georgiou**

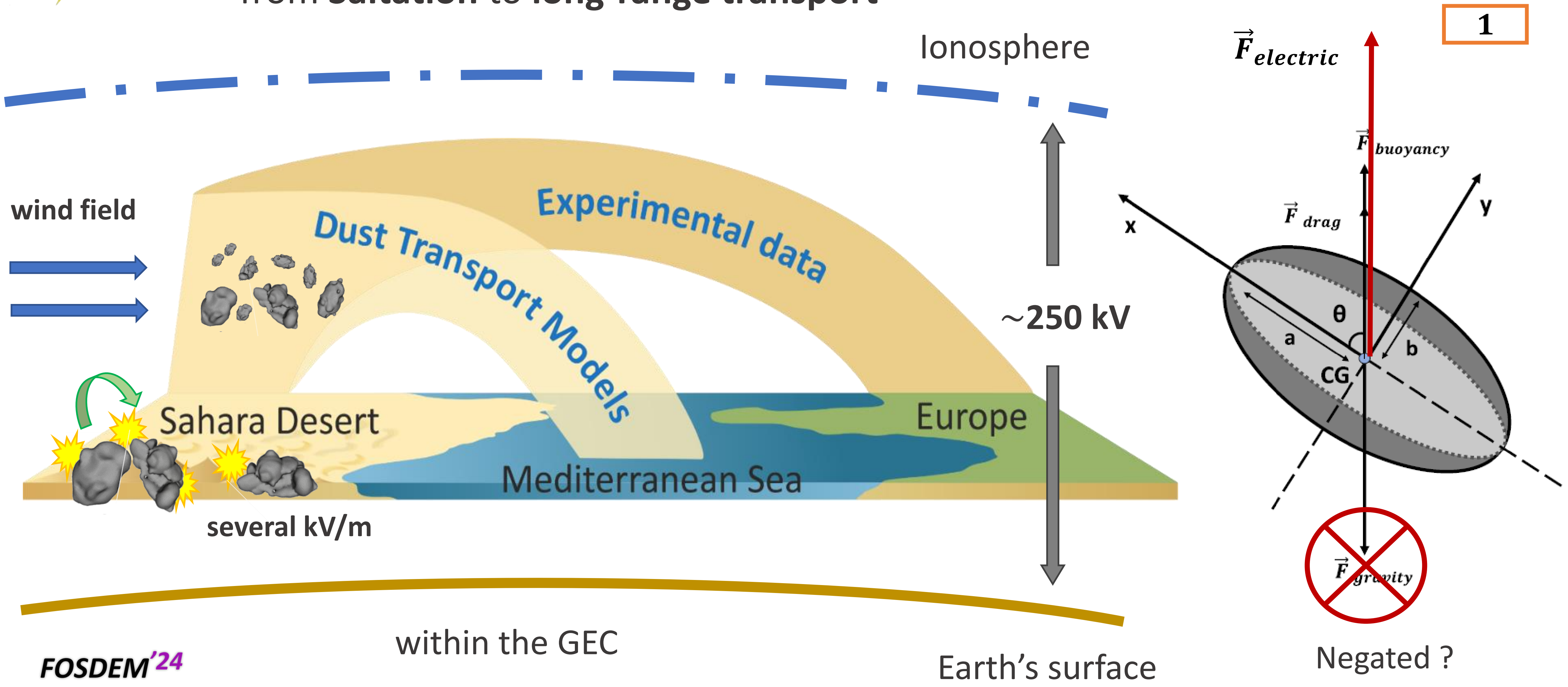
FOSDEM’24

Agenda

- Intro – Scientific Question
- Why open source ?
- Sensor Assembly & Testing
- Observations
- Data sharing
- What next ?

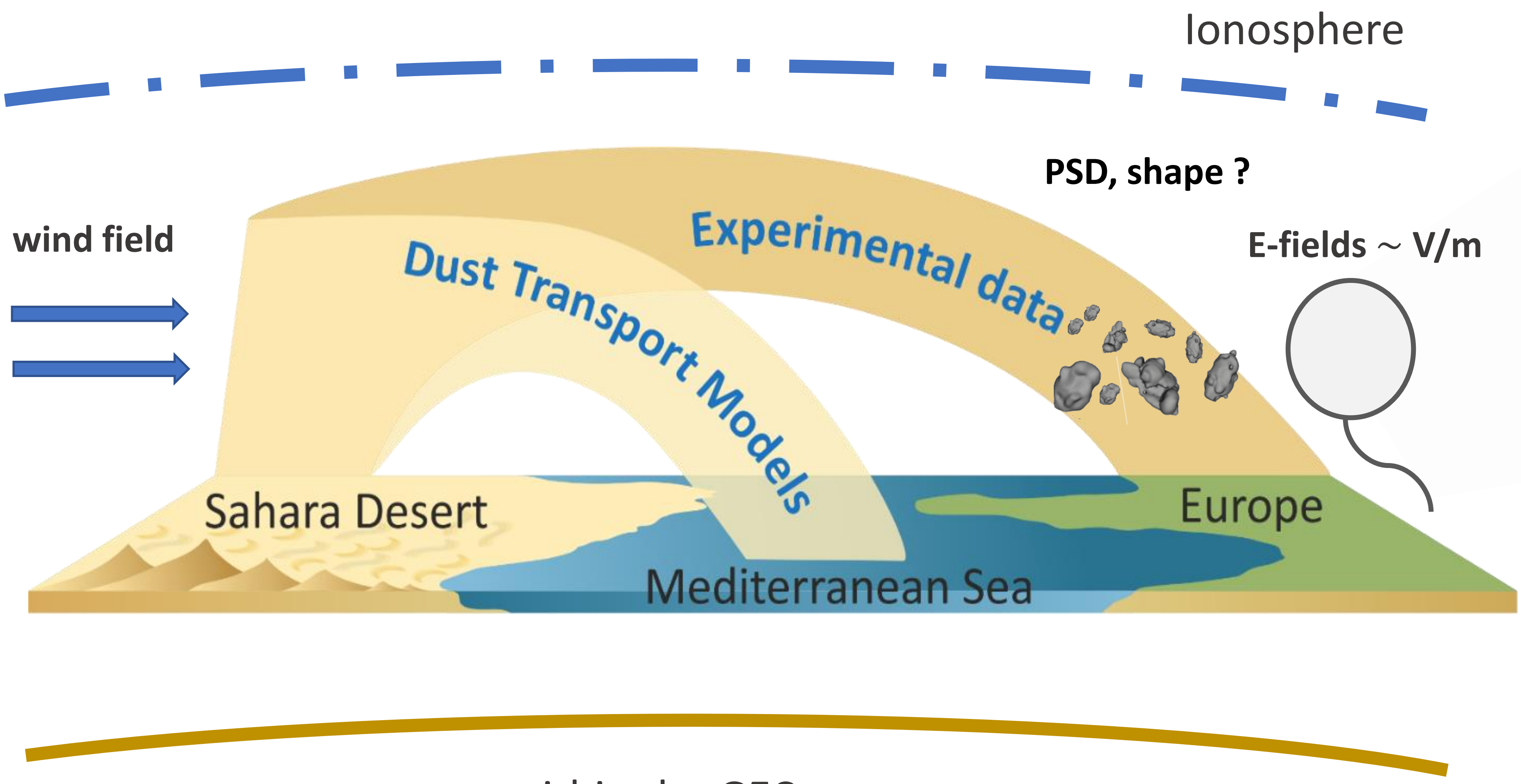
Impact of Atmospheric Electricity on particle dynamics

from **Saltation** to **long-range transport**



Impact of Atmospheric Electricity on particle dynamics

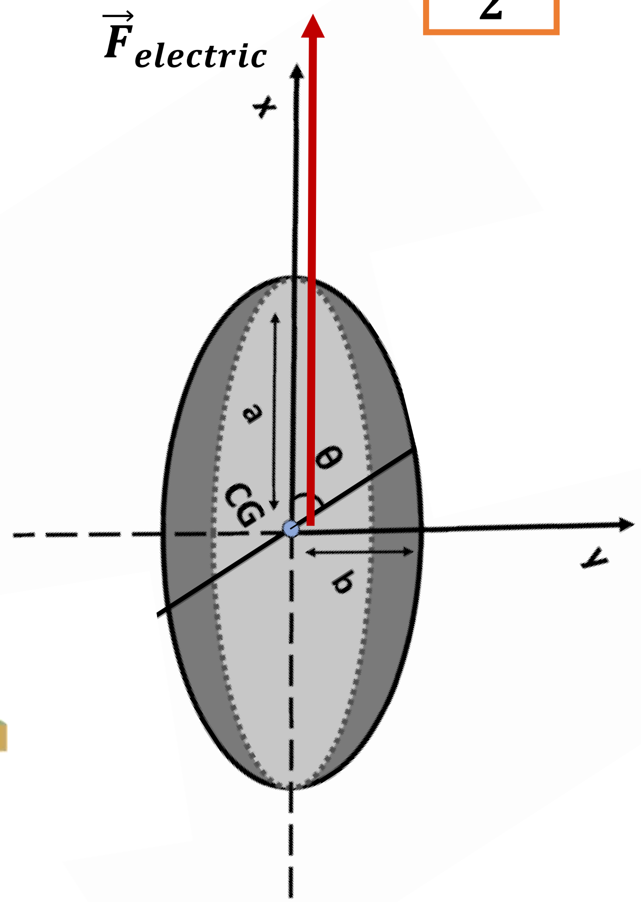
from **Saltation** to **long-range transport**



within the GEC

Earth's surface

2



Vertically oriented ?

New developments

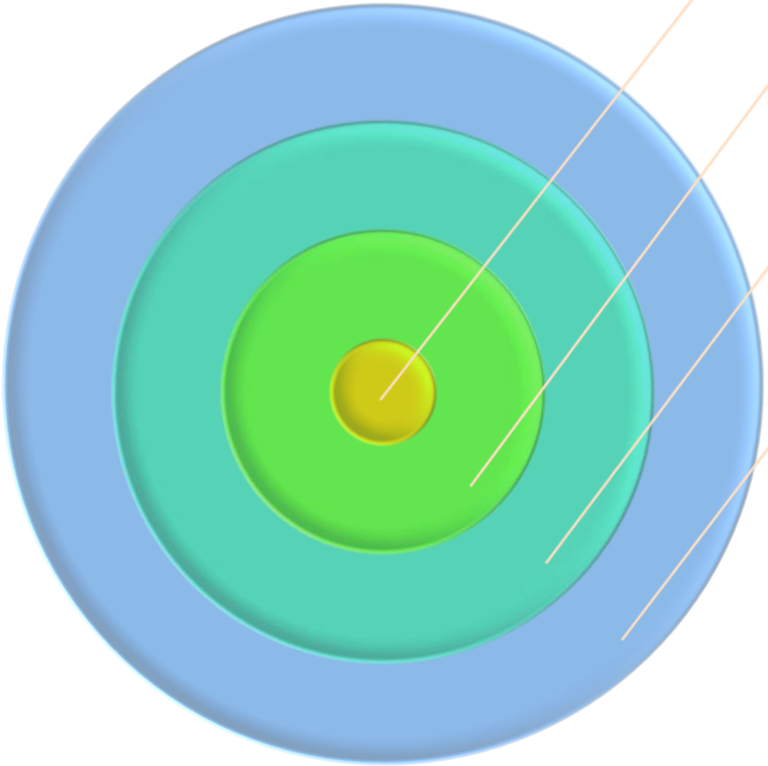
Can we verify our hypothesis through observations **?**

Vertical profiling of the electrical properties

"Hope clouds observation."

Frank Herbert, Dune

Why open-source ?



Challenge & create **transparency**

Biased **reward systems**

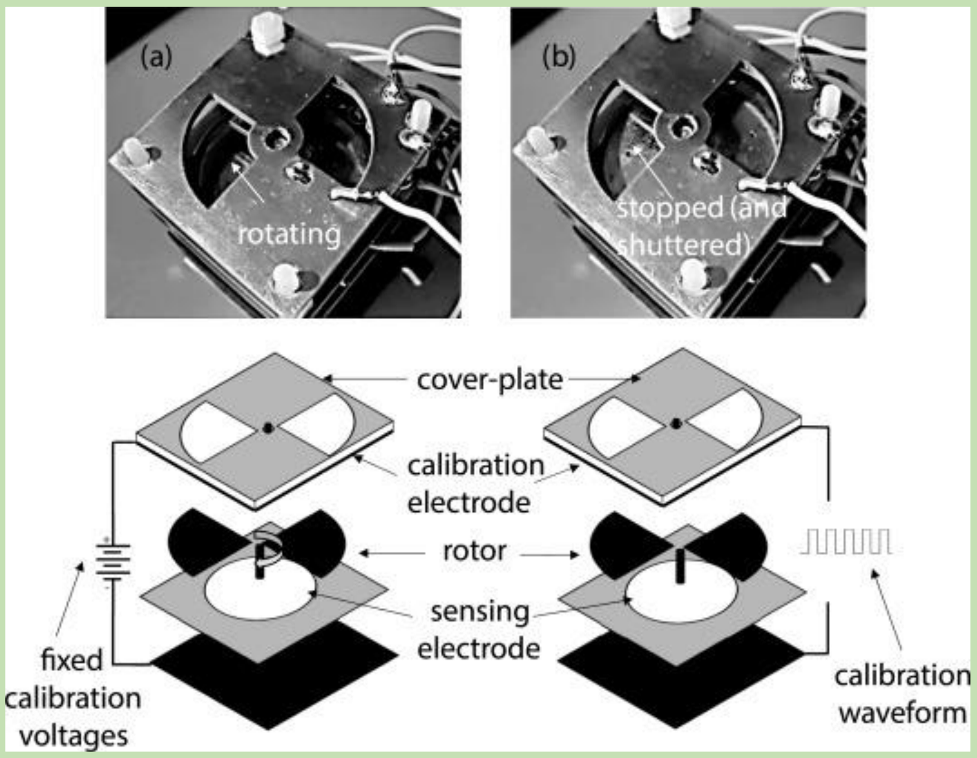
Concerns on **personal recognition**

Traditional **academic structures**

What we found up till then was fairly **closed** …

Different implementations of miniature fieldmills

- Not tested **balloon-borne** platforms

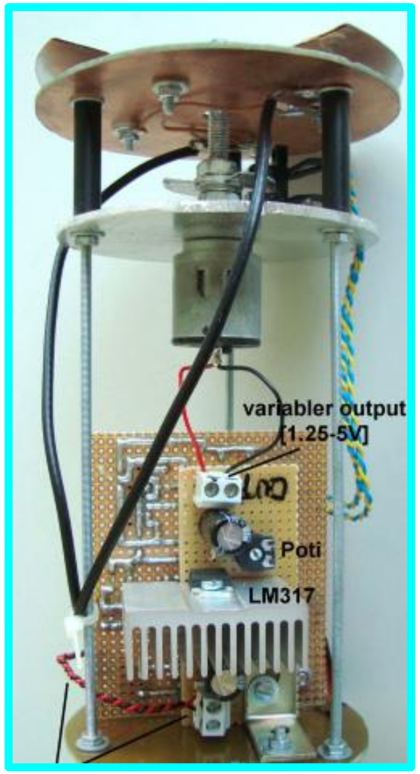


- Sketchy or non-existent schematics

[Harrison et al., 2020]

& [Cui et al., 2017]

[Homebrewed stuff]



- Non portable

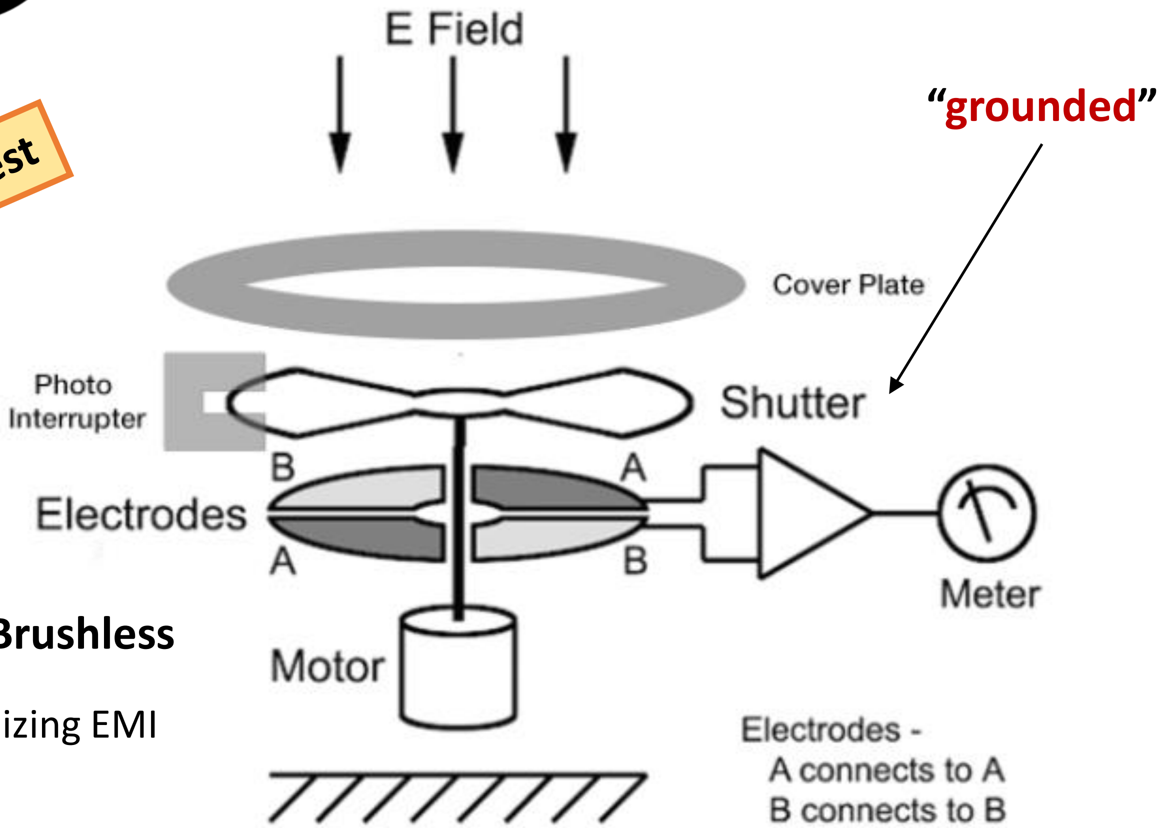
Not sensitive to **Fair weather** fields

[Cool project]

@ArcAttack/**FieldMill-PCB**

MiniMill: Principle of operation & Design

latest



DC Brushless

minimizing EMI

MPU-6050 gyro

Low rpms for optimal sensor response

- Periodical screening of a **sensing electrode**
- The **induced charges** for an effective sensing area $S(t)$:

$$Q(t) = \sum_{S} q = \varepsilon_0 E S(t)$$

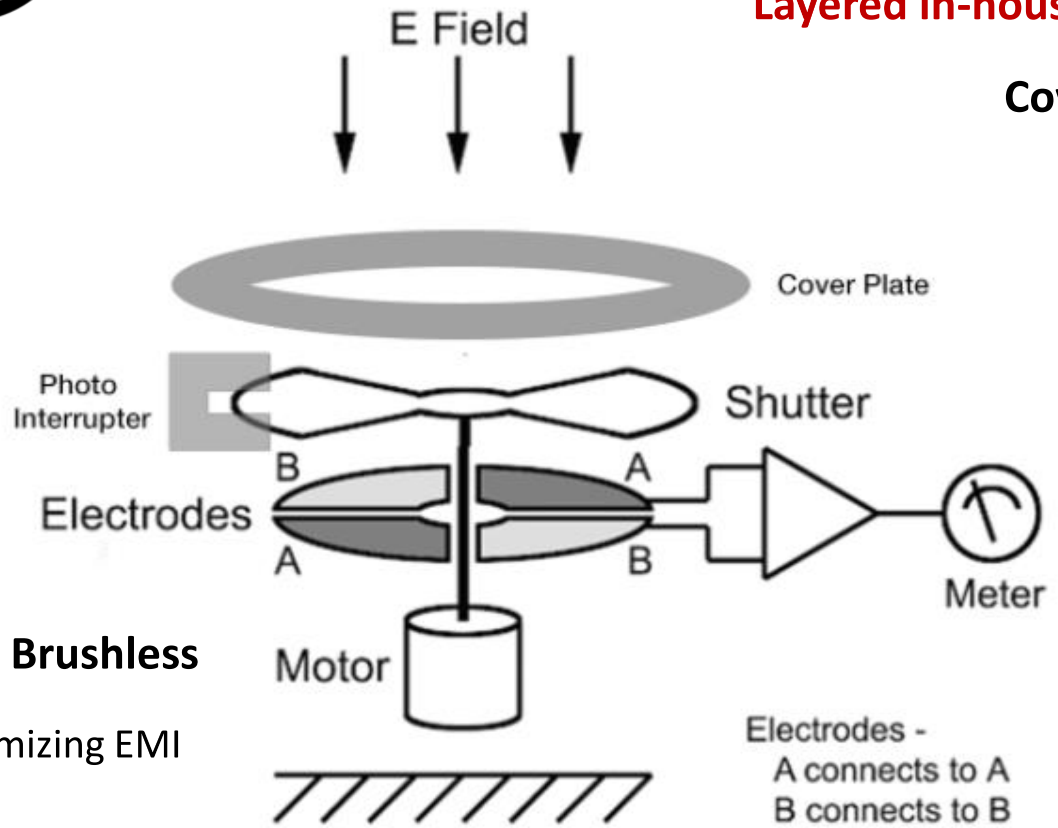
S depends on the circular sector angle

and the **induced current** directly related to the **vertical E-field** will be:

$$i(t) = \varepsilon_0 E \frac{dS(t)}{dt}$$

- **Measured voltage** is twice the amplified output voltage from each electrode (differential measurement)

MiniMill: Principle of operation & Design

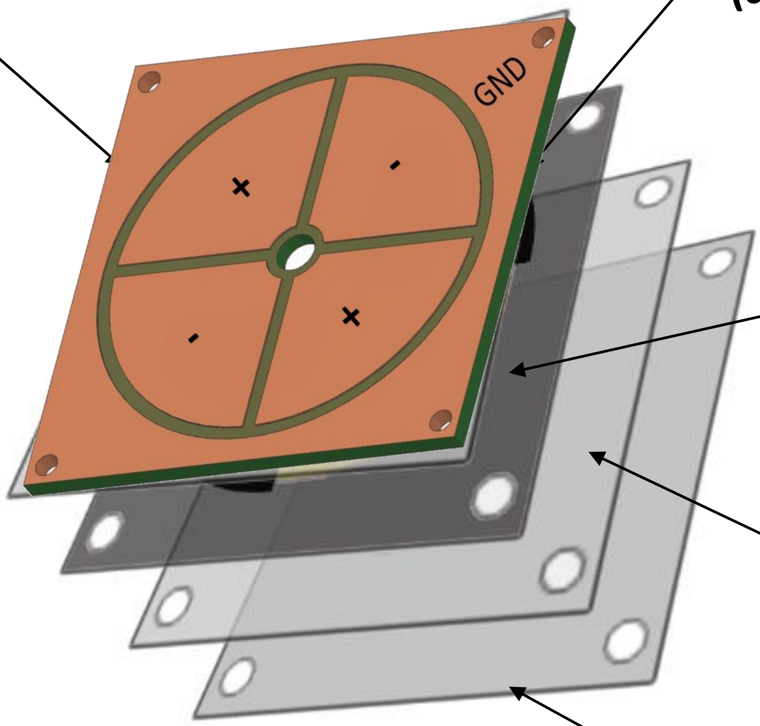


DC Brushless

minimizing EMI

ADC microcontroller- **Serial** transmission

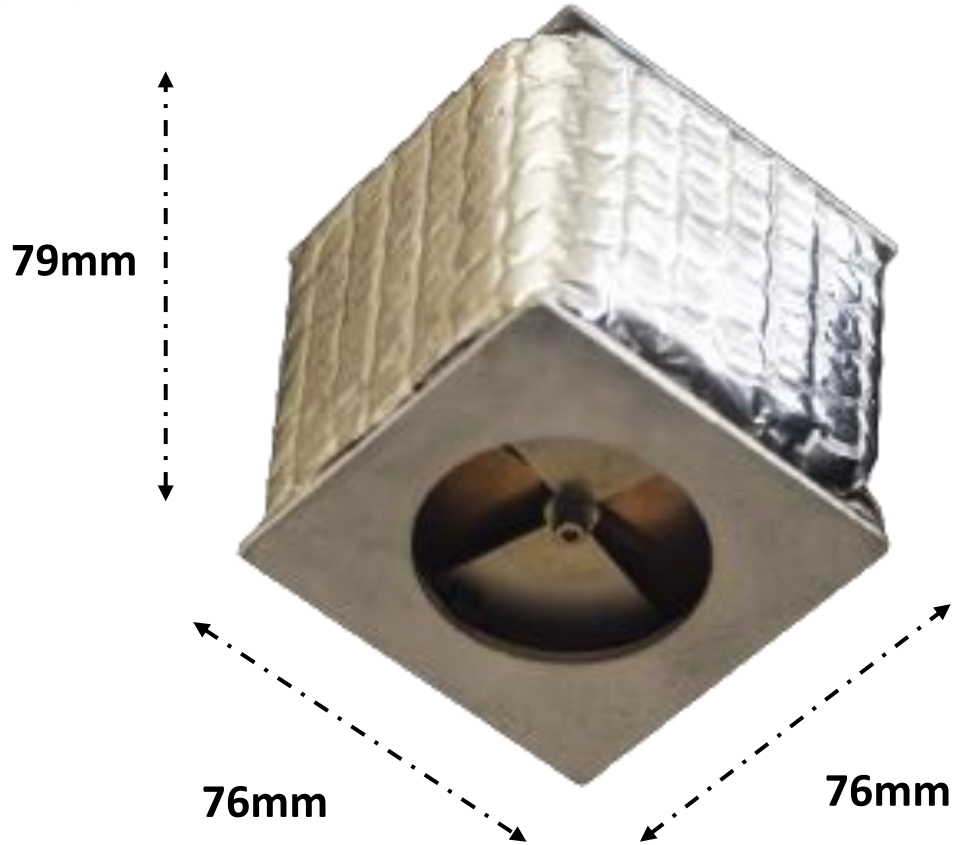
Layered in-house sensor assembly



ǂ eventually not deployed due to parasitic fields

Sensor specs & limitations

With **thermal** shielding



E-field strength (V m^{-1})
(during radiosonde ascend /descend)

Pros

- ✓ Robust design; easy to reproduce; low-cost (~ 100€ each)
- ✓ Lightweight (~ 300gr) ; disposable
- ✓ Direct measurement; angular position measurements
- ✓ Sensitivity ± 2.3 mV per V m^{-1}; range ± 2.4 kV

Cons (cur. design)

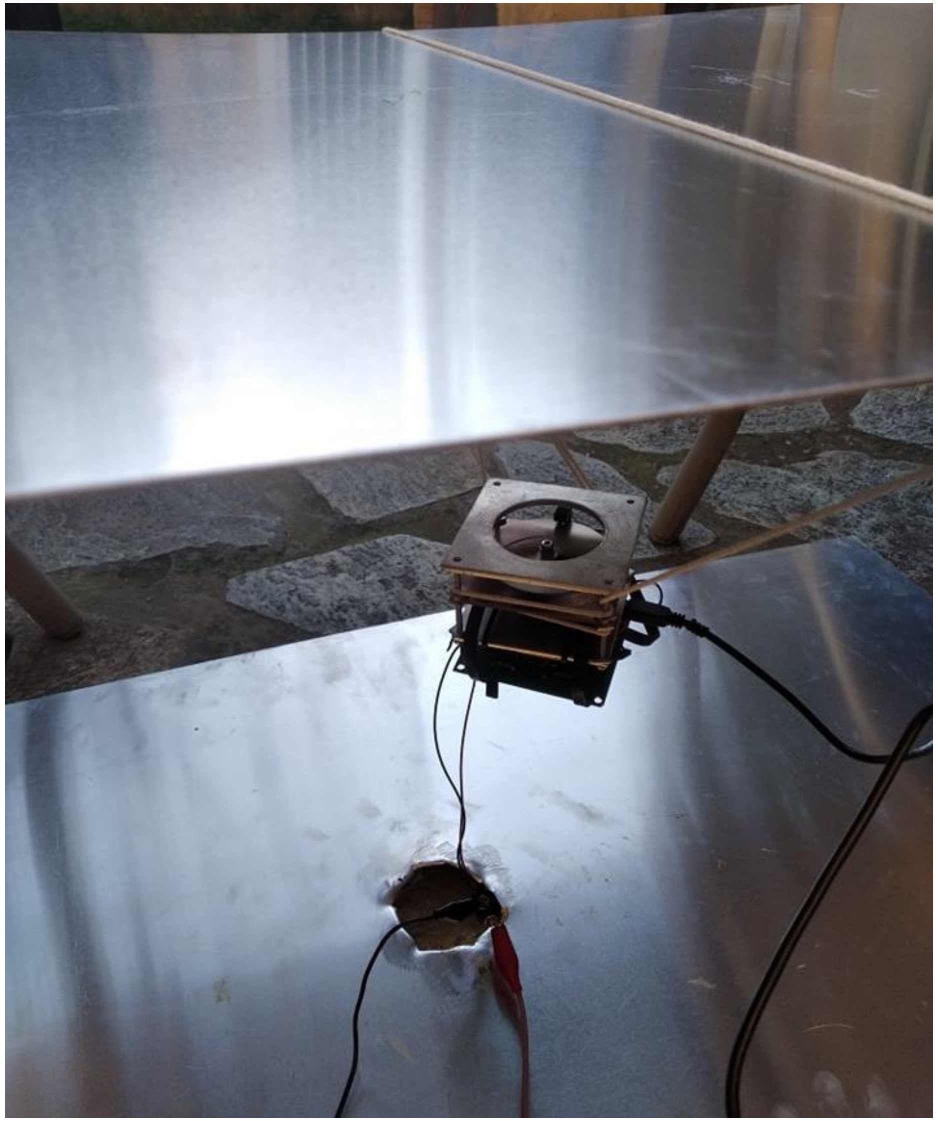
- × Bulky electronics
- × slightly overestimates E-field (parasitic fields, horizontal slide or $E_{x,y}$ components)
- × Limited operation temperature at - 50°C
- × Max. altitude of operation ~ 16 Km due to motor/battery freeze

Calibration tests (completed)

i. **Hard vibration** test, ii. **Temperature** resilience, iii. **FW** response vs commercial **Fieldmill**, iv. **Faraday cage** response, v. **parallel plates calibration** & vi. test **radiosonde flight**

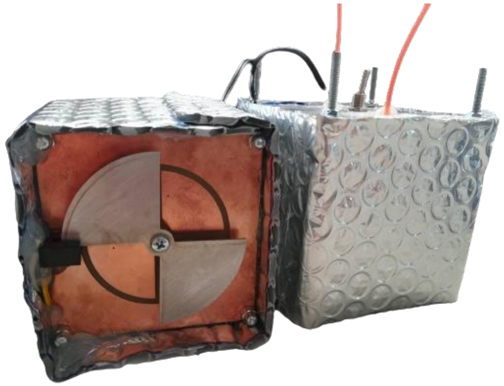
❖ **Easily tethered to Small Unmanned Aircrafts (SUAs)**

Standard calibration set-up

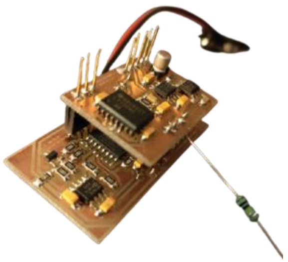


Parallel plates with fixed voltage input

Telemetry through UART



Daisy chaining to **GRAW** meteorological radiosonde



2^{nd} sensor pings the MiniMill

(P, T, H, U, GPS)

XDATA protocol

Pin	Use	Comment	Connect To
1	N/C	The red wire	No connection
2	Rx		Microcontroller UART Tx
3	Tx		No connection
4	GND		Ground

○ Standalone on the **ground**:

Serial to text output

“**trick**” GS sensor ID

Data storage

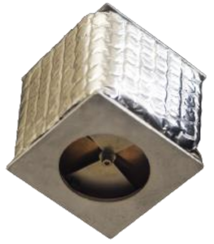
decoder

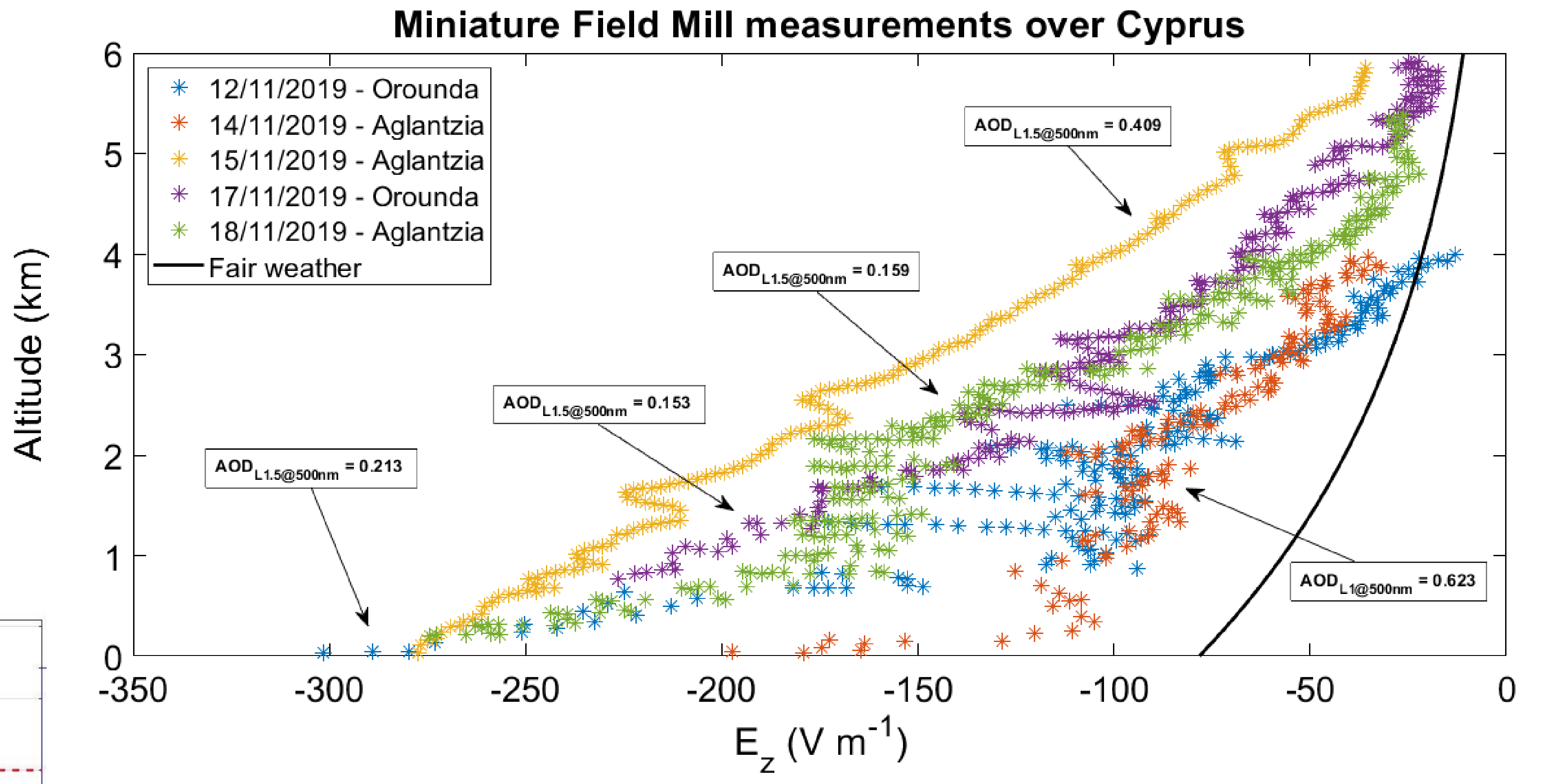
○ **Raw** data

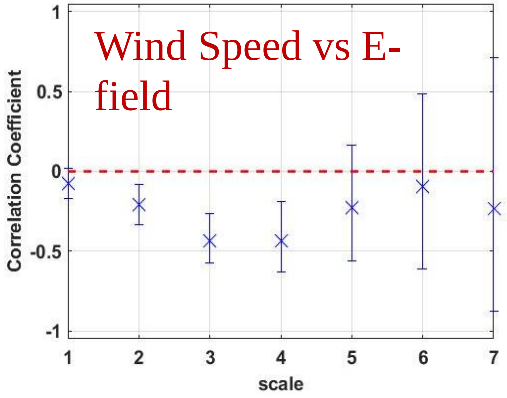
Mass production for experimental campaigns

Observations of Dust Electrification

Preparatory ASKOS experiment



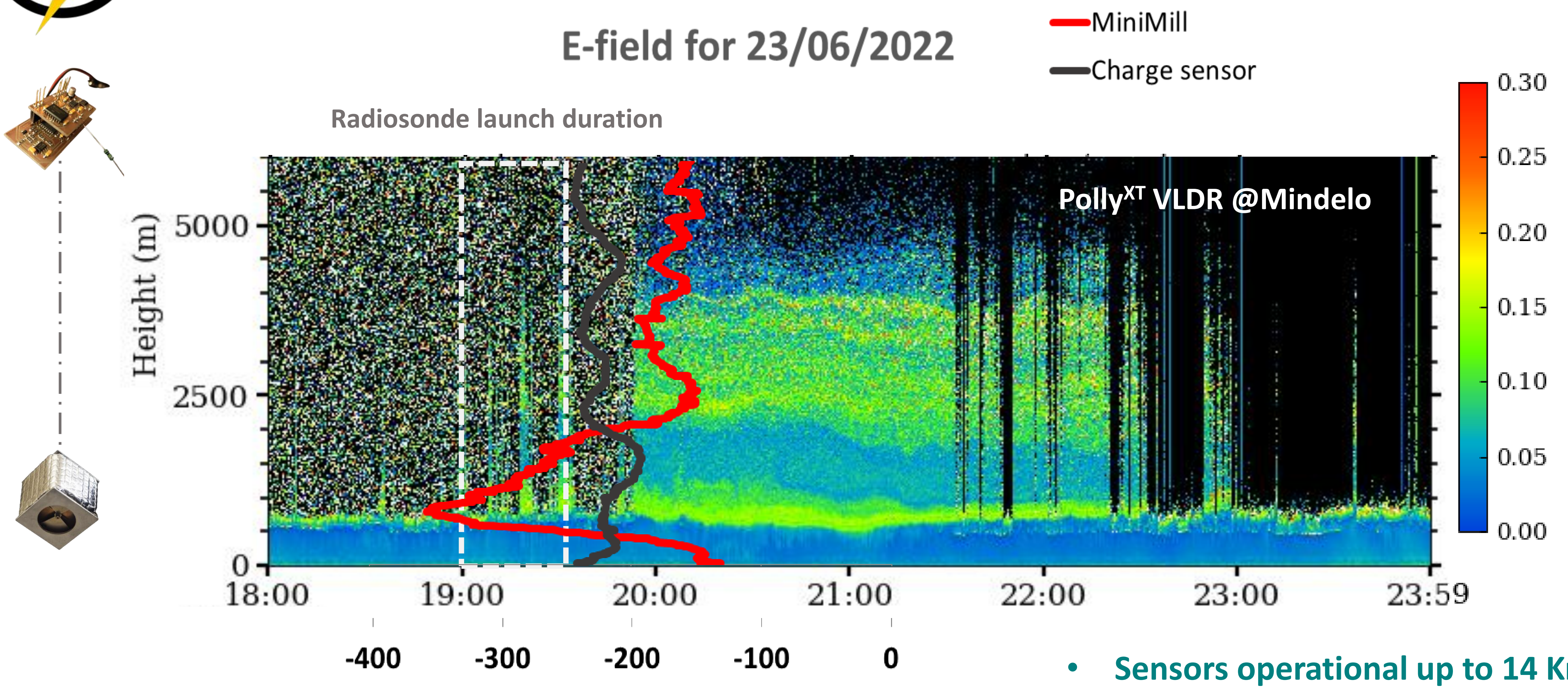




Maximal overlap discrete wavelet transform

→ *anticorrelation* in medium scales

Observations of dust electrical properties



- **Sensors operational up to 14 Km**

(due to battery decay)

Data sharing platforms

Full repo: https://github.com/NOA-ReACT/electricity-sensors

Do contribute !

Raw Dataset
publicly available

Calendar
publicly available

open Repo

Open Research challenges

- **<u>Standardization Issues</u>:** lack of it may lead to variations in sensor specs, affect reliability and consistency of collected data.
- **<u>Documentation Quality</u>:** crucial for project success. Incomplete or unclear documentation can hinder the assembly process, especially for those not familiar with the specific hardware.
- **<u>Technical Expertise</u>:** for sensors assembly might be required. Ensuring that contributors or users have access to adequate support and resources for troubleshooting technical issues is crucial.
- **<u>Data Calibration and Validation</u>:** for regulatory compliance with research organizations
- **<u>Funding Constraints</u>:** often on limited budgets - testing, and QC can be a challenge, impacting the overall success.
- **<u>Long-Term Support</u>:** addressing hardware issues, releasing updates, and ensuring ongoing compatibility with evolving technologies.

Key takeaway

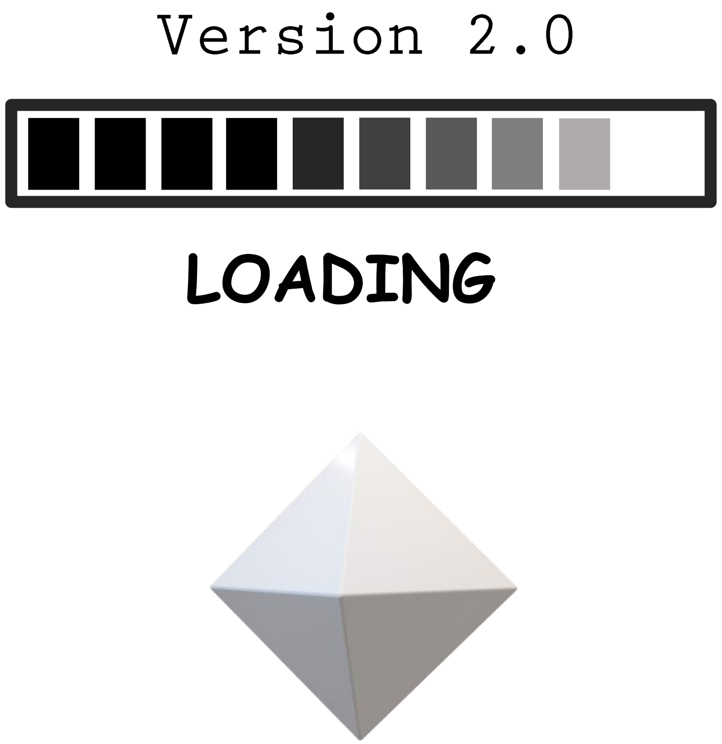
Eventually, *do we answer the sc. initial question* ?

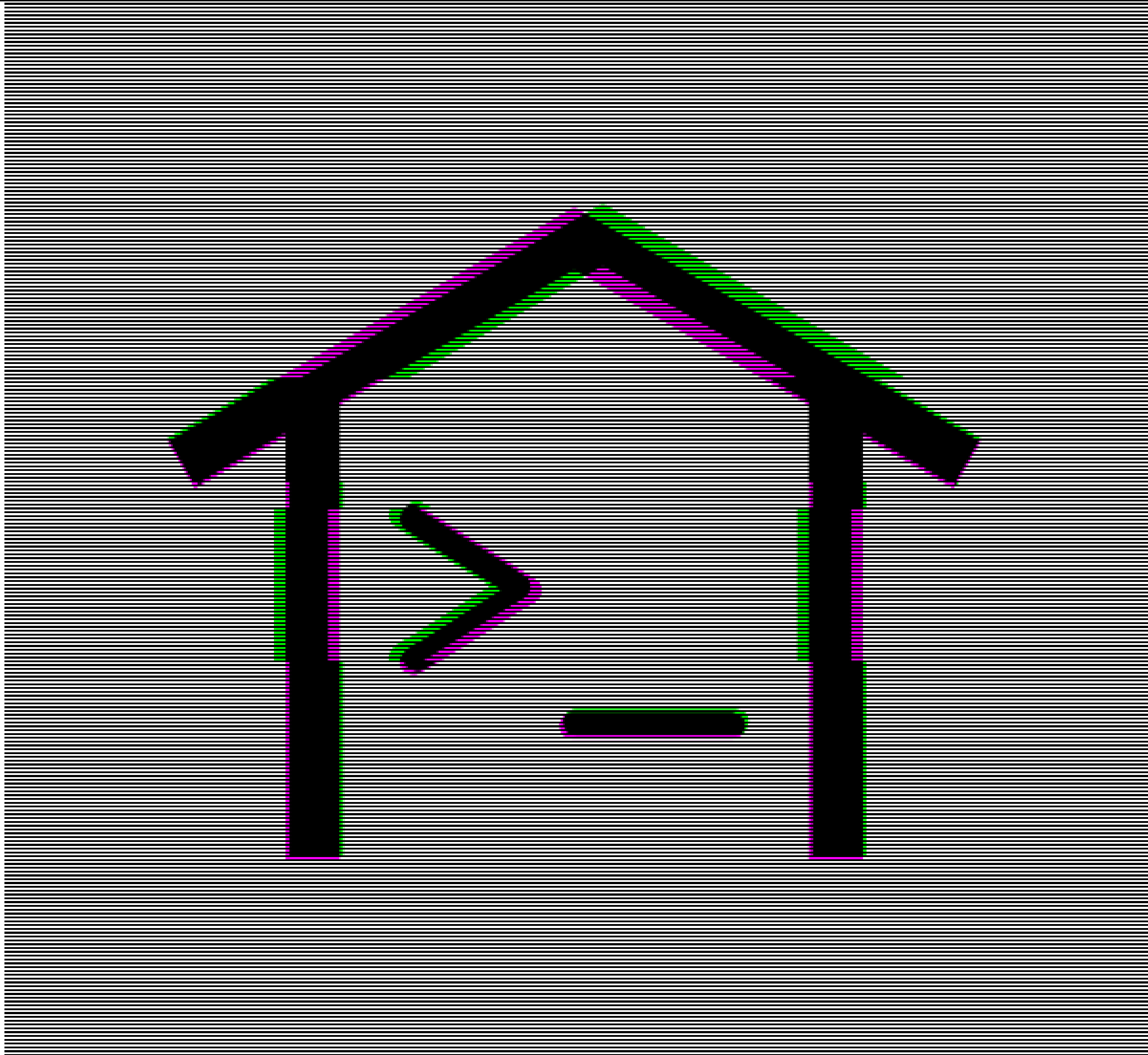
Yes, **MiniMill** current version produced fairly nice results !

In retrospect:

Electrical Properties seem to **not play a significant role** on the long-range transport of desert dust 👎🏿

What next ?





What next ?

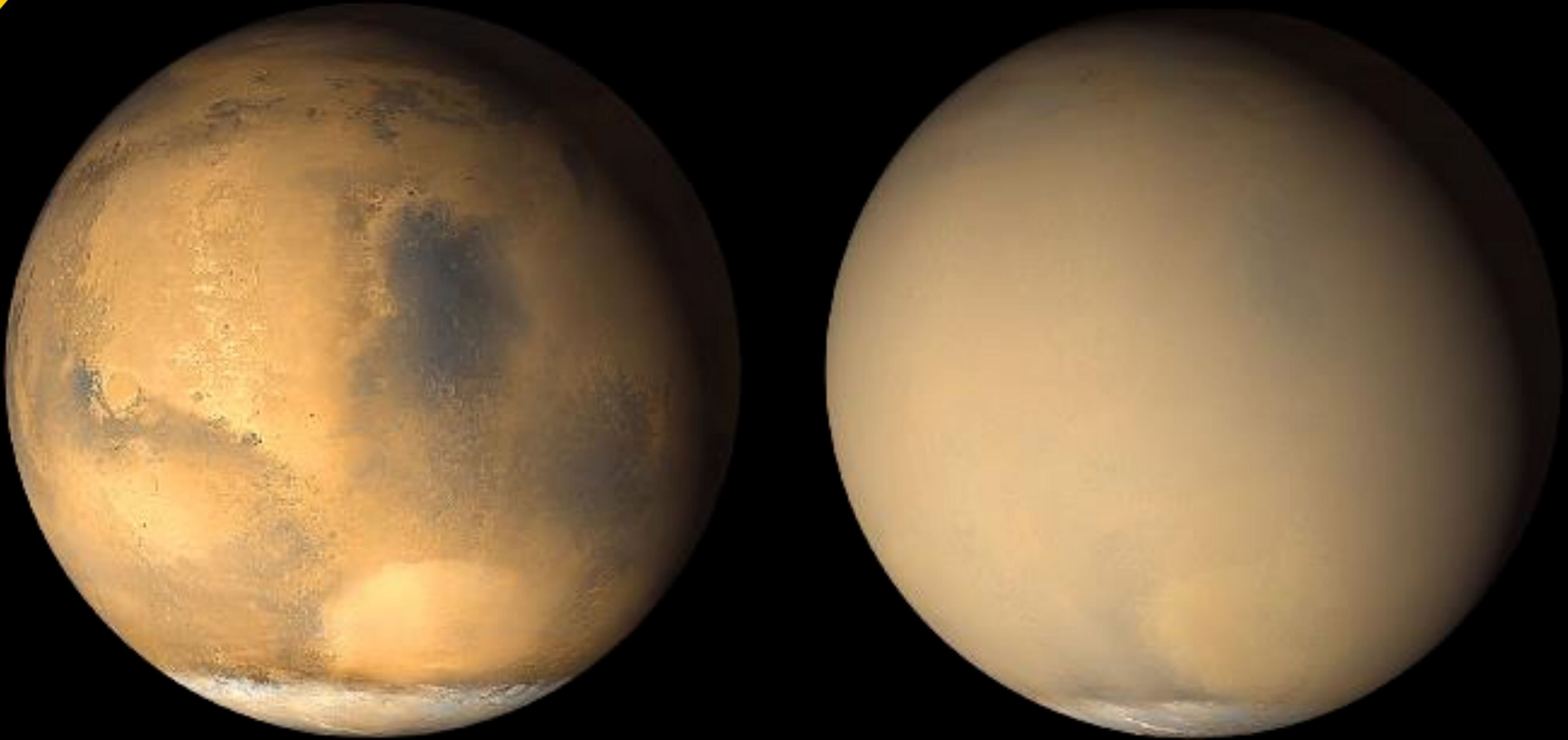


Image cred. NASA


Thank you... all !
vdaskalop@noa.gr
@ModusElectrificus

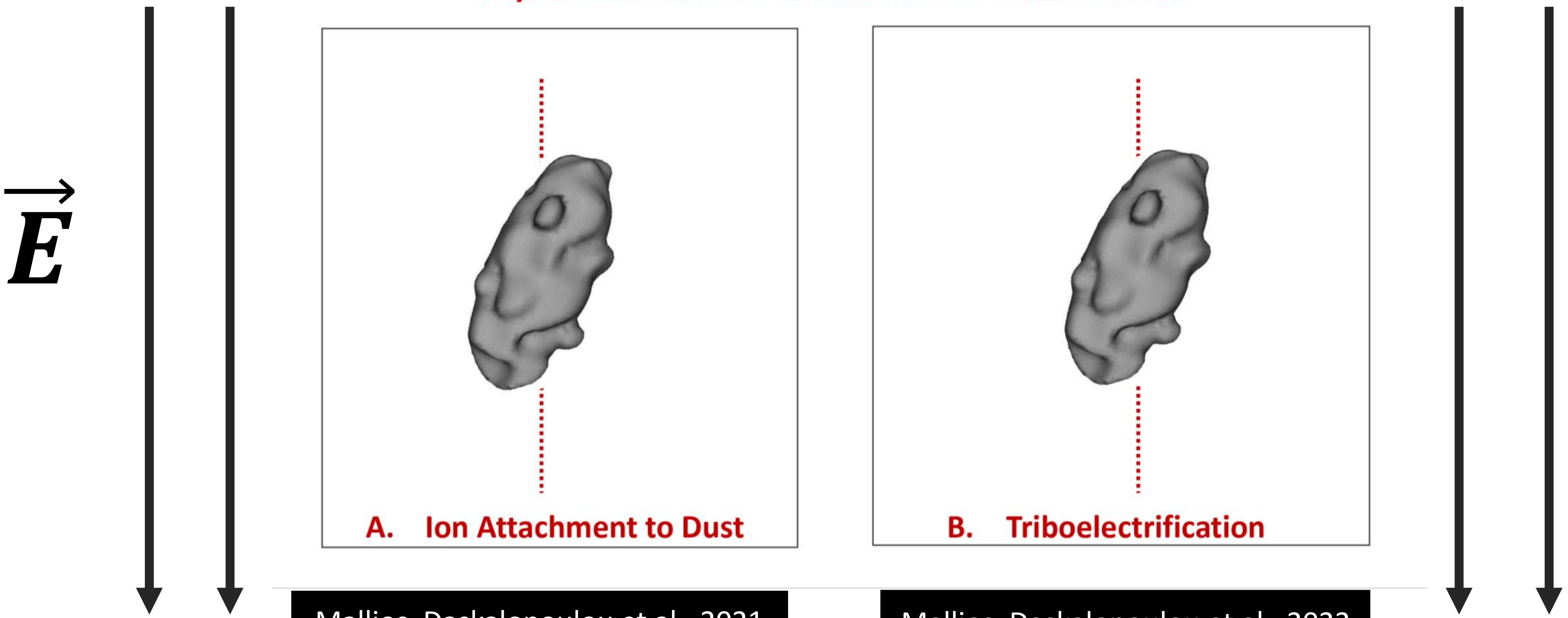
MiniMill specs

Baud Rate		
Pre Radiosonde	115200	
On Radiosonde	9600	8 data bits, no parity, one stop bit (8N1)
RPMs:		
~ 40 Hz	2400 (average)	
Sampling Rate		
Pre Radiosonde	9500 Samples Per Second	
On Radiosonde	1 Sample Per Second	
Modes:		
1) w/ Accelerometer	MPU6050 - Triple Axis Gyroscope & Accelerometer IMU	
2) No rotational information		
Motor:	FlyCat 2204/260kV Brushless Motor	
Speed controller:	XXD HW30A 30A Brushless Motor ESC	
PCB type:	multilayered	
PCB1	PTH, 70X70mm, FR4 1mm, 35μm	
PCB/Electrode	Electrode Deck with copper plating	
Microcontroller type		
Arduino Nano CH340		
Operating environment	(implemented configuration)	
Temperature	up to - 40°C	
Altitude	msl to ~ 13km	
Humidity	to 100%	

Dynamic range	
single sensitive channel	
Noise	
Zero field error	~ 2mV
Field uncertainty	± 3V/m
Sensitivity	1 ADC cnt, ± 2.3mV per V/m
Resolution	0 - 1024 ADC cnts, ± 2.4kV
Accuracy	1 ADC cnt
Bandwidth (dB)	through UART
	Radiosonde defined bandwidth
Physical	
Mass	250 gr
Power	9V batteries (DC in)
Cosumption	< 160mA
Electrode Deck	
Radius	45mm
Shutter	
Radius	5.83cm
Thickness	1mm
Distance from the Electro	4mm
Cube Dimensions:	
Height	79mm
Length	76mm
Width	76mm

Dust Charging parametrizations

Physical Mechanisms of Dust Particle Electrification



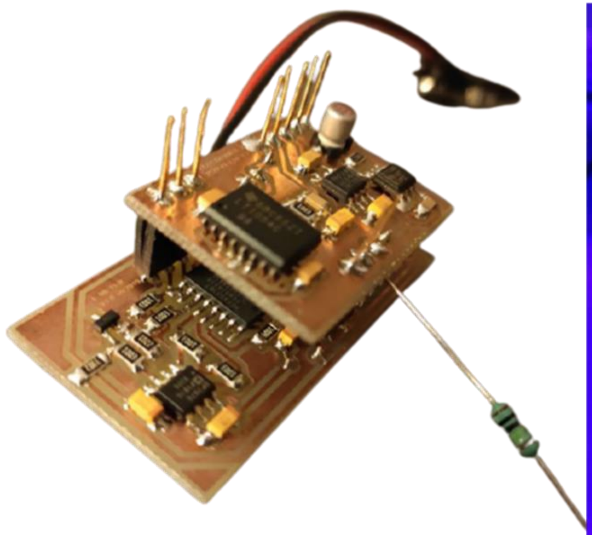
Mallios, Daskalopoulou et al., 2021

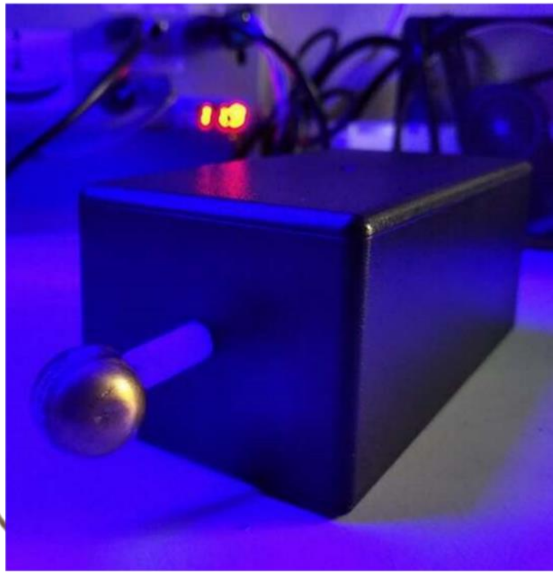
Mallios, Daskalopoulou et al., 2022

Ion attachment dominates in the case of transported dust layers

New developments for Vertical profiling: Space Charge sensor

With **hollow** brass electrode





Nicoll et al., 2013, 2011

Charge density (C m^{-3}) & **E-field strength** (V m^{-1})

(during radiosonde ascend /descend)

☛ **GitHub: @NOA-ReACT/electricity-sensors**

Pros

- ✓ easy to reproduce; low-cost; disposable
- ✓ Single spherical electrode; regular de-charging
- ✓ Indirect measurement (can provide a better estimation of E-field)
- ✓ Sensitivity ± 2.3 mV per V m^{-1}; Resolution ± 2.3 mV; Accuracy <0.5%

Cons

- × Induced + particle charges
- × Extensive calibration periods;

$$\rho = \frac{\varepsilon_0}{d_{eff}} \frac{1}{w} \frac{dV_{out}}{dt}$$

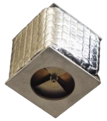
Calibration tests (completed)

i. **Hard vibration** test, ii. **Temperature** resilience, iii. **FW** response vs commercial **Fieldmill**, iv. **Faraday cage** response, v. **parallel plates calibration** & vi. test **radiosonde flight**

❖ **Tethered to MiniMill for balloon-borne launches**

Convergence of E-field measurements

MiniMill and Charge sensor parallel post-processing

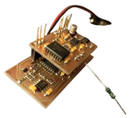


Correction to the MiniMill E-field for the **rotational position** of the sensor:

$$E_z^{cor} = E_z^{meas} \cos \boldsymbol{\theta_{roll}} \cos \boldsymbol{\theta_{pitch}}$$

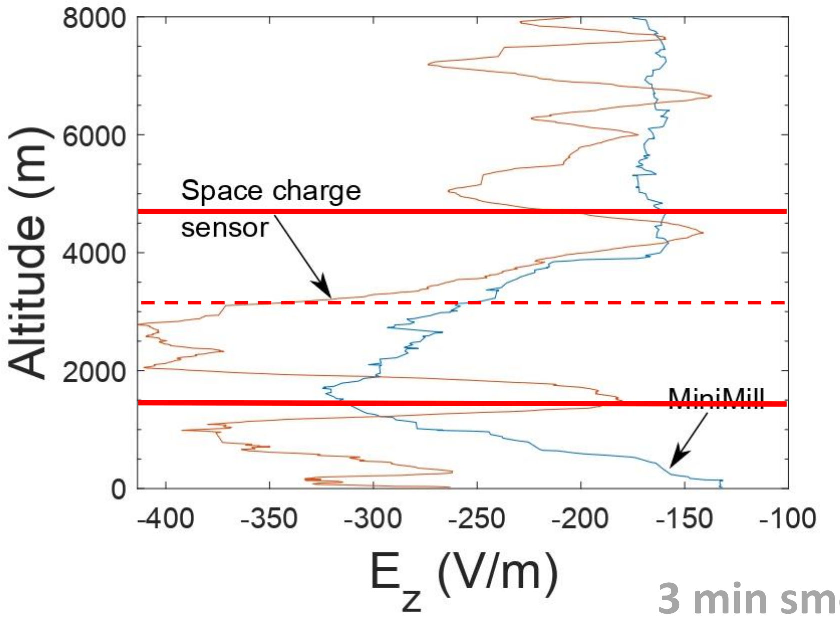
✓ **Good agreement**

Solving **Poisson** for the charge sensor measurement subsections (with SOR):

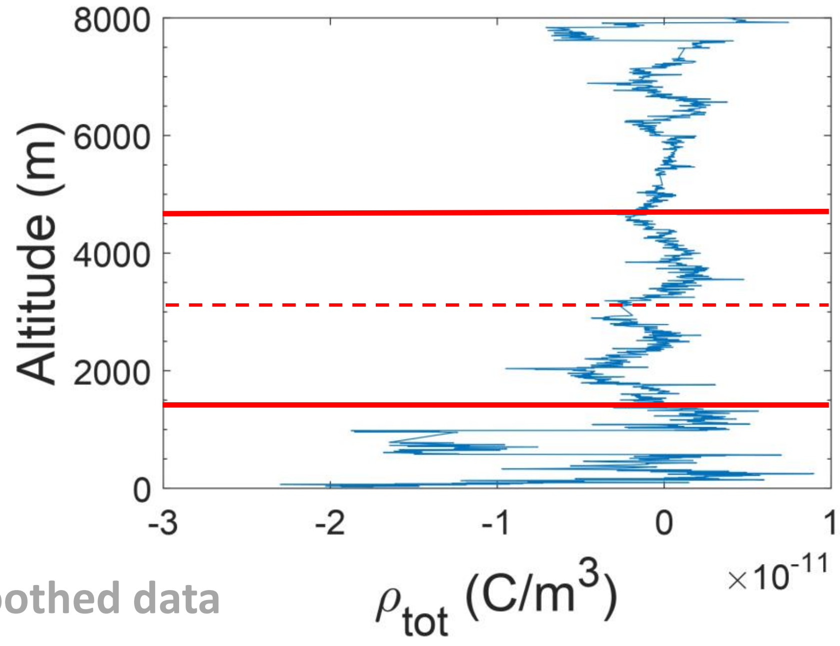


$$\frac{d^2V}{dz^2} = -\frac{\rho_{tot}}{\varepsilon_0} \quad \text{assuming} \quad E_z = -\frac{dV}{dz}$$

✓ **Layer Stratification**



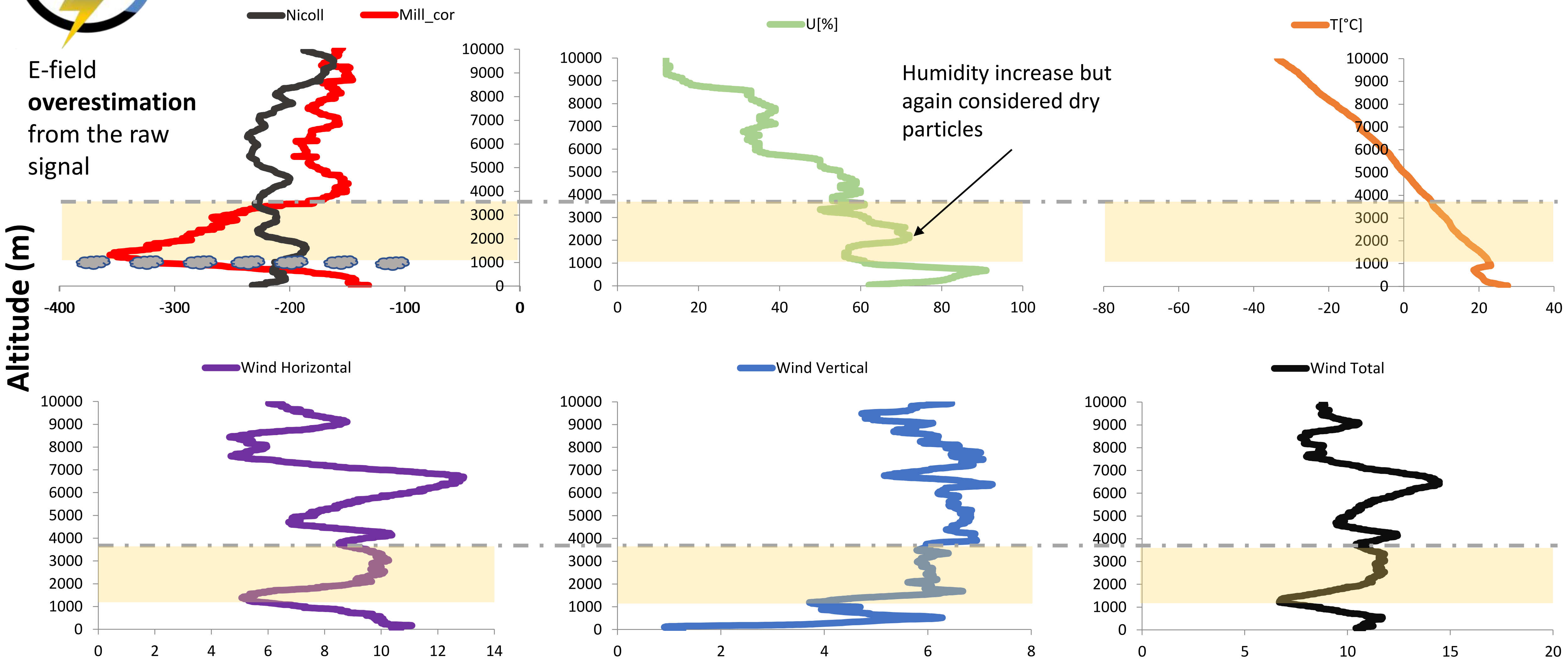
3 min smoothed data



✓ **Charge sensor's better**

Electrical Profiling comparison to meteorological parameters

E-field **overestimation** from the raw signal



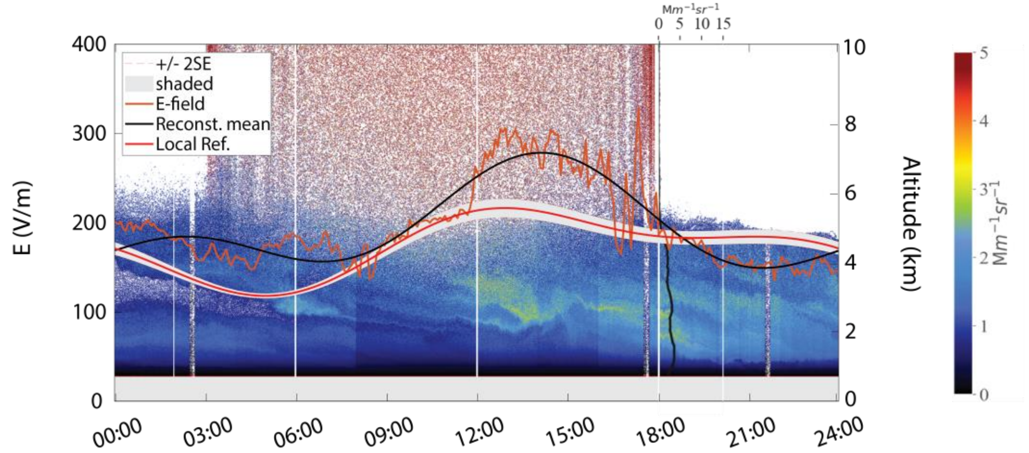
Correlation of the E-field to **wind direction** → **New methodology** for data processing

Electrified dust layers detection with Ground-based Methods

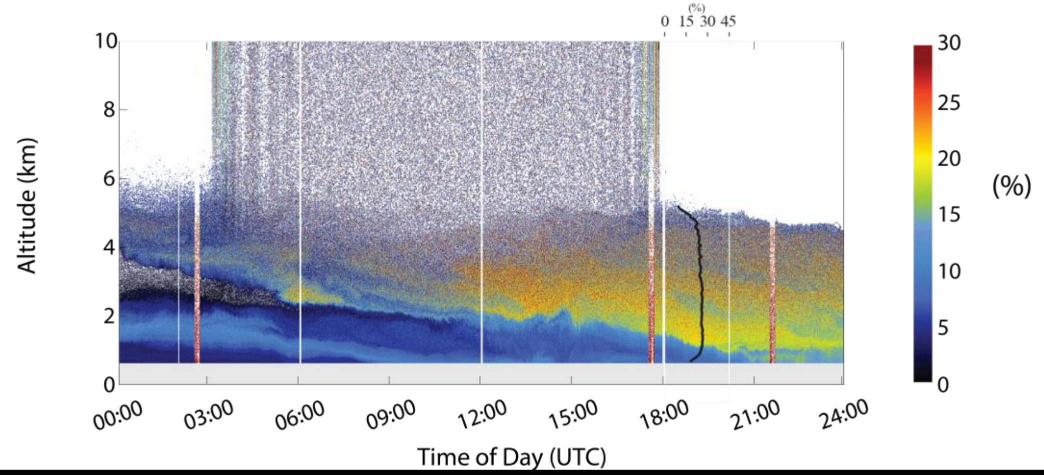
✓ First ever synergistic measurements between a **lidar** and a **ground-based fieldmill**

Electrically active

Electric Field strength vs Attenuated Backscatter Coefficient at 532nm - July 25th 2017, Finokalia

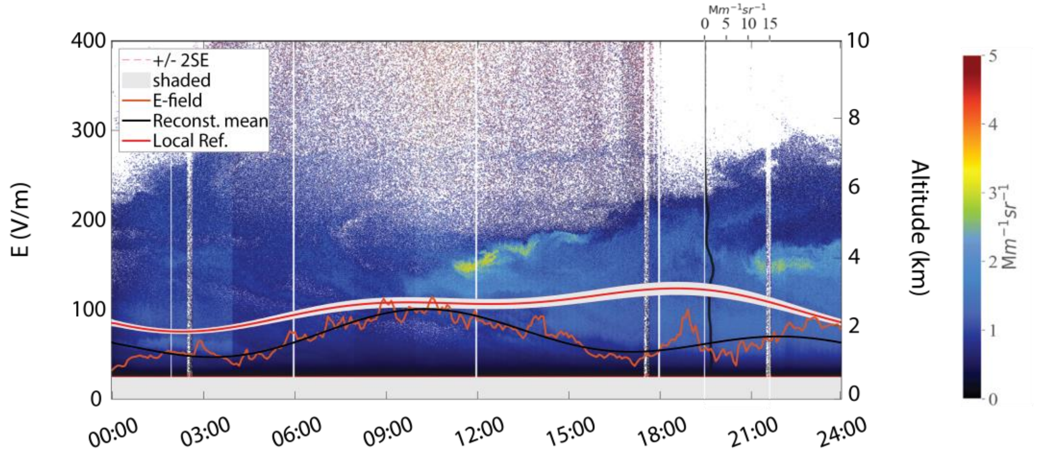


Polly[XT] Volume Linear Depolarization Ratio at 532nm - July 25th 2017, Finokalia



Electrically inactive or small charge separation

Electric Field strength vs Attenuated Backscatter Coefficient at 532nm - June 23rd 2019, Antikythera



Polly[XT] Volume Linear Depolarization Ratio at 532nm - June 23rd 2019, Antikythera